IAGOS

Vertical distribution, seasonality and tropophericity of icesupersaturated air masses in the northern mid-latitudes from regular in-situ observations by passenger aircraft

A. Petzold[1], S. Rohs[1], M. Rütimann[1], P. Neis[1,3,$], F. Berkes[1,§], H.G.J. Smit[1], M. Krämer[2], N. Spelten[2], P. Spichtinger[3], P. Nedelec[4] , A. Wahner[1]

1 Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research 8 – Troposphere, Jülich, Germany

2 Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research 7 – Stratosphere, Jülich, Germany

3 Johannes Gutenberg University, Institute for Atmospheric Physics, Mainz, Germany

4 CNRS Laboratoire d'Aérologie, and Université Paul Sabatier Toulouse III, Toulouse, France

$ now at CGI Deutschland B.V. & CO. KG, Frankfurt, Germany

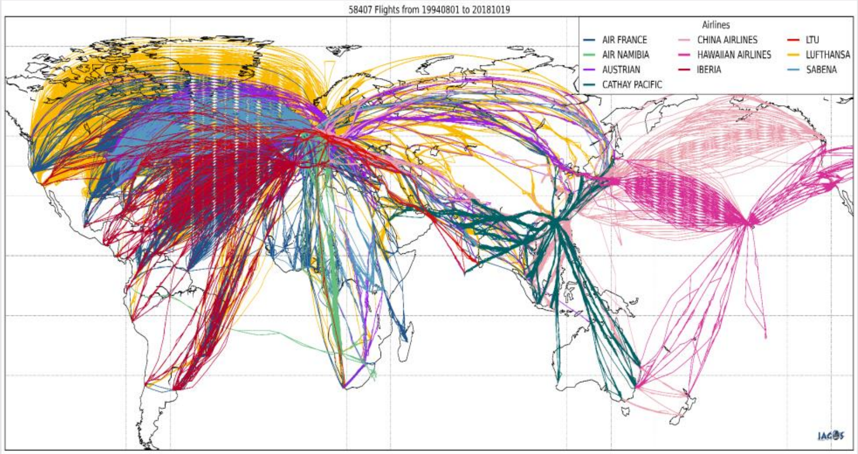
§ now at P3 solutions GmbH, Aachen, Germany

Published: DOI: 10.5194/acp-2019-735.

Contact: a.petzold@fz-juelich.de or www.iagos.org

Global-Scale Atmospheric Composition Dataset from Instrumented Passenger Aircraft by MOZAIC and IAGOS

www.iagos.org



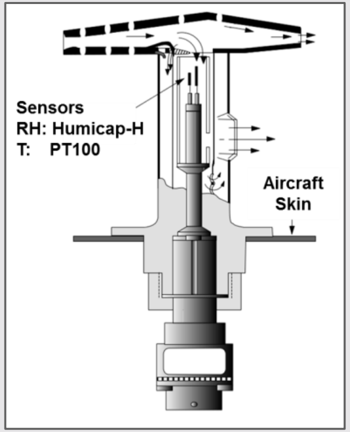
IAGOS-CORE (historical MOZAIC: 1994 - 2014)

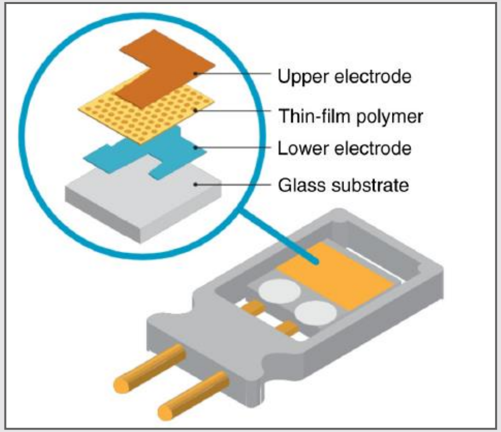
- Regular *in situ* global-scale monitoring of H_2O, O_3, CO, NO_x, CO_2, CH_4, aerosols, clouds
- Long-term deployment envisaged (> 20yrs)
- Today, 7 long-haul aircraft (IAGOS-CORE) and one flying laboratory: IAGOS-CARIBIC since 1997
- European Research Infrastructure for Earth observation by passenger aircraft since 2014

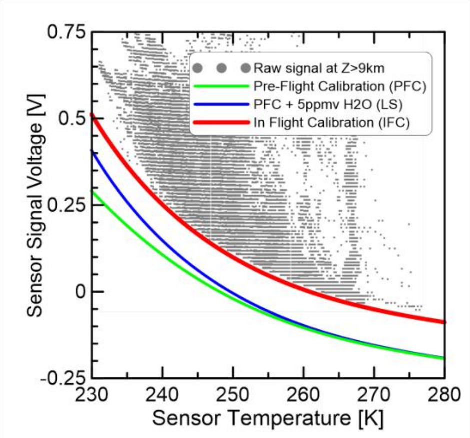
- Open data policy; visit www.iagos.org
- Provision of data in near real time for Copernicus and other services
- Long time series available for
  - tropopause temperature (> 20 yrs)
  - O_3 , H_2O, RH_{ice} (> 20 yrs)
  - CO (> 15 yrs)
  - NO_x (2 yrs)

MOZAIC/IAGOS Capacitive Hygrometer (MCH/ICH)

www.iagos.org







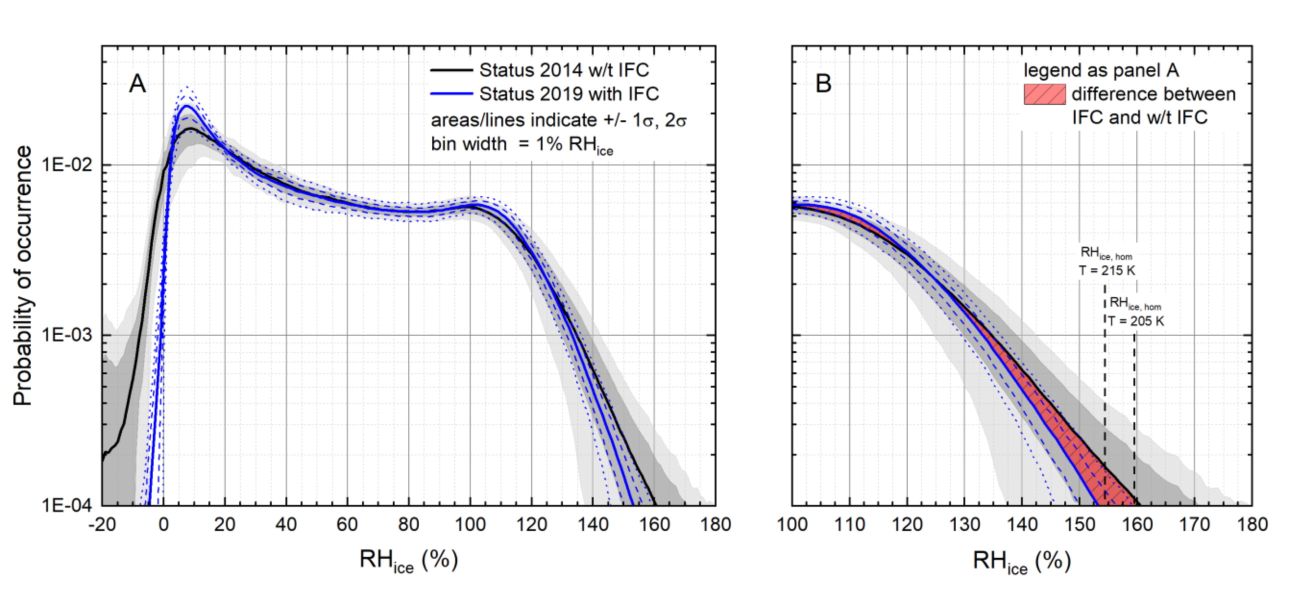
- Hydroactive Polymer Film which adsorbes H_2O
- Capacitance depends on relative humidity (RH_{liquid}); C= 180-220 pF
- Low maintenance requirements
- Calibrations traceable to frost point mirror
- In-flight blind intercomparison: 5% RH_{liquid} uncertainty, LOD approx. 20 ppmv

- MCH/ICH show drift during operation
- Flight sequences in dry air masses (RH < 10%) are used to correct for drift
- In-flight Calibration (IFC) developed 2008
- IFC applied to MOZAIC reanalysis (2014)

Helten et al., JGR 1998; Neis et al., Tellus B 2015, Smit et al., ACP 2014

PROBABILITY DENSITY FUNCTIONS OF RHICE

www.iagos.org



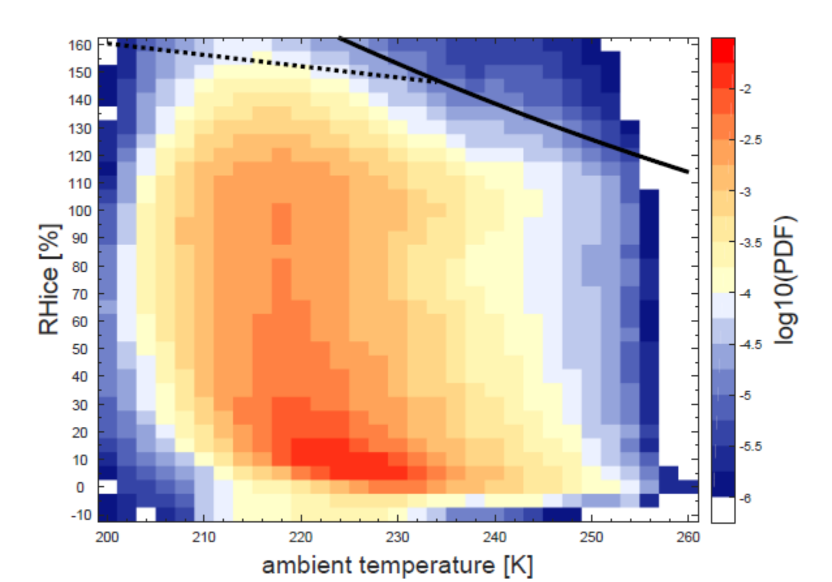
(a) Averaged probability density functions of RH$_{ice}$ for the entire MOZAIC period from 1995 to 2010

(b) Zoom into the region of ice-supersaturation

=> The 2σ - variability of observed ISS at 10^{-4} occurrence probability reduces from max. 180% RH$_{ice}$ (without IFC) to 155% RH$_{ice}$ (with IFC). This fits into the range of homogeneous freezing thresholds at typical extratropical tropopause conditions of RH$_{ice,hom}$ = 158% at 205 K to RH$_{ice,hom}$ = 154% at 215 K (Koop et al., 2000). Respective values without IFC applied exceed the homogeneous nucleation threshold significantly.

MOZAIC: Distribution of RH_{ICE} (1995-2010)

www.iagos.org

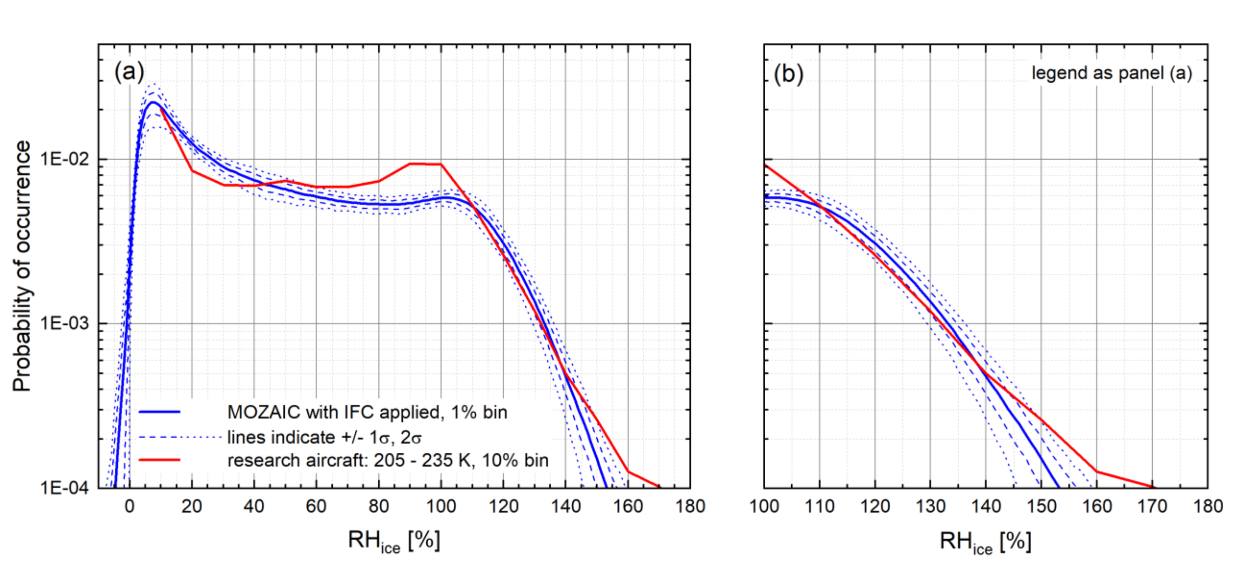


- IFC applied , Colour indicates the probability of occurrence;
- The lines represent water saturation (solid line; Sonntag, 1994) and the threshold RH_{ice} for homogeneous ice nucleation (dotted line; Koop et al., 2000; Kärcher and Lohmann, 2002).

=> RH_{ice} observations remain inside the physical boundaries let by the water saturation line and the line for homogeneous ice nucleation

AVERAGED PROBABILITY DENSITY FUNCTIONS OF RH_{ICE}

www.iagos.org



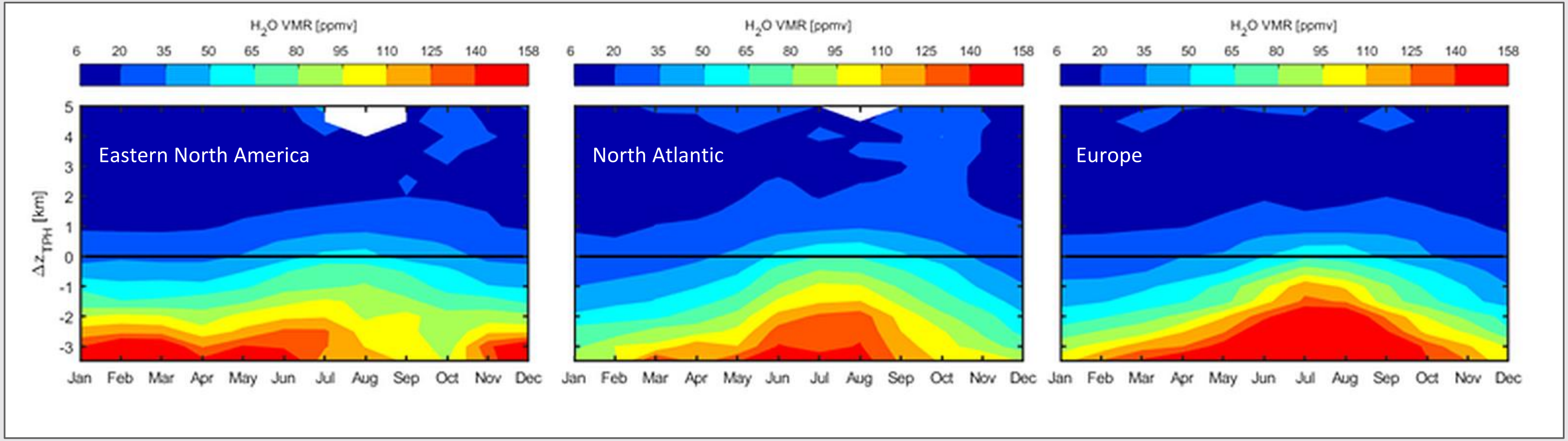
(a) averaged probability density functions (PDFs) of RH_{ice} for the entire MOZAIC period from 1995 to 2010

(b) and the zoom into the region of ice-supersaturation with the IFC method applied (blue lines) and RH_{ice} PDF from 250 research aircraft flights collected in the Jülich In-situ Airborne Database (Krämer et al., 2016).

=> **Both PDFs show excellent agreement within the uncertainty ranges, particularly for the regime of ice supersaturation. The differences for RH_{ice} near 100% are caused by preferred sampling of ice clouds and contrails during the field campaigns.**

WATER VAPOUR VERTICAL VARIABILITY

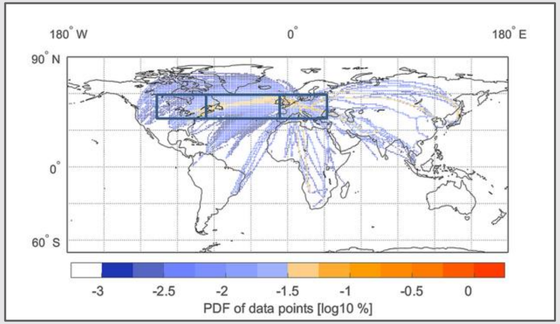
www.iagos.org



Seasonal variation of 15 yrs. mean monthly median H_2O VMR [ppmv]

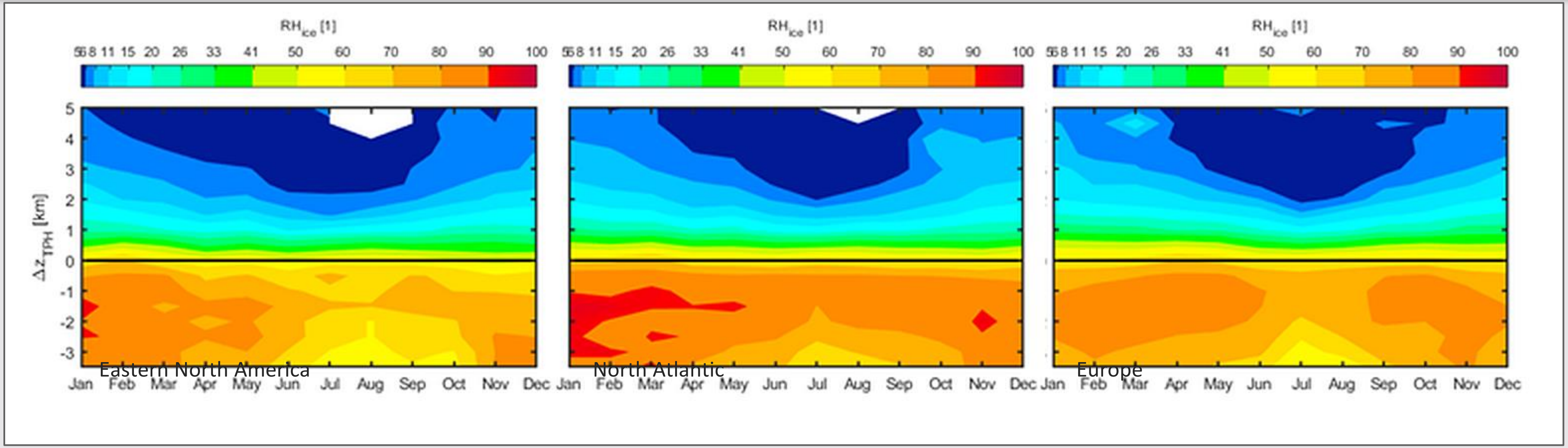
- Latitudes 40°N to 60°N; regions (from left to right) Eastern North America (105°W to 65°W), North Atlantic (65°W to 5°W) and Europe (5°W to 30°E)
- Distribution relative to the WMO thermal tropopause height z_{TPH}

=> Clearly visible moistening of the LMS in summer



RH_{ICE} VERTICAL VARIABILITY

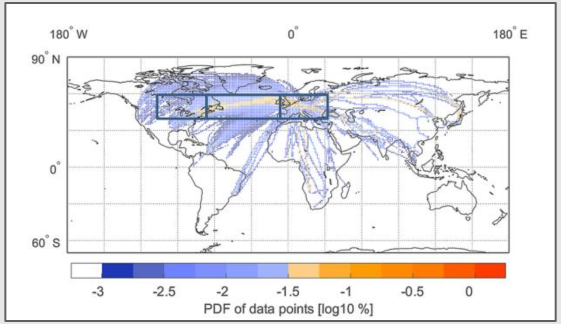
www.iagos.org



Seasonal variation of 15 yrs. mean monthly median RH_{ice} [%]

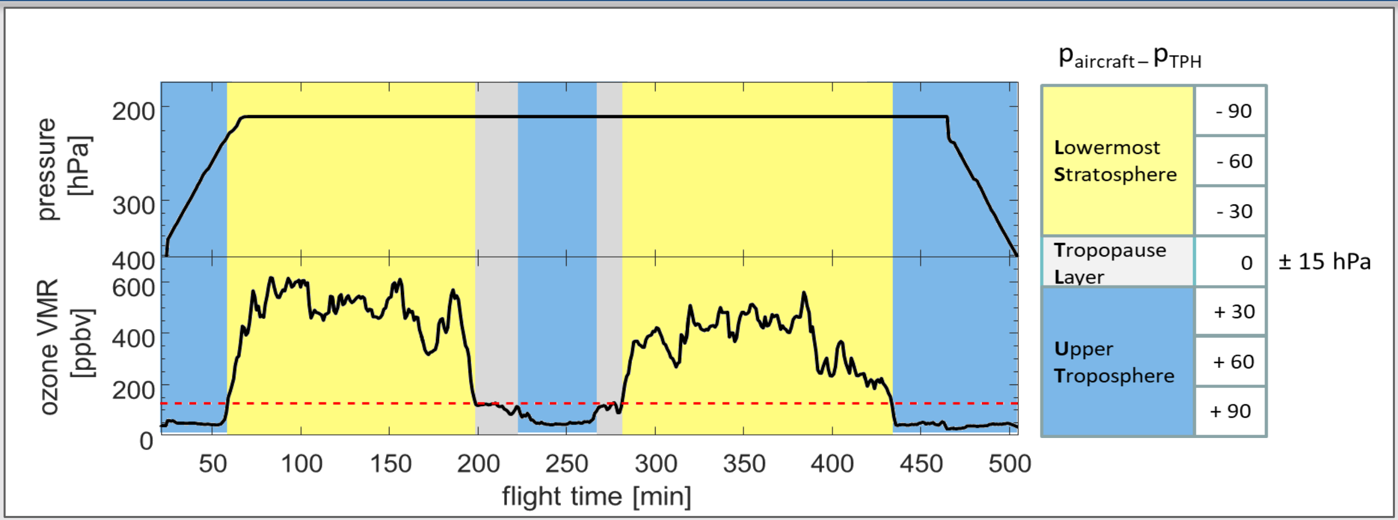
- Latitudes 40°N to 60°N; regions (from left to right) Eastern North America (105°W to 65°W), North Atlantic (65°W to 5°W) and Europe (5°W to 30°E)
- Distribution relative to the WMO thermal tropopause height z_{TPH}

=> RH_{ice} distribution patterns are similar for all regions



THE IAGOS DATA SET – VERTICAL COORDINATES

www.iagos.org



- Seasonal and regional variation of the tropopause height requires relative altitude coordinates.
- Data are grouped relative to the dynamical or thermal tropopause height ($p_{dyn.TPH}$; $p_{therm.TPH}$)

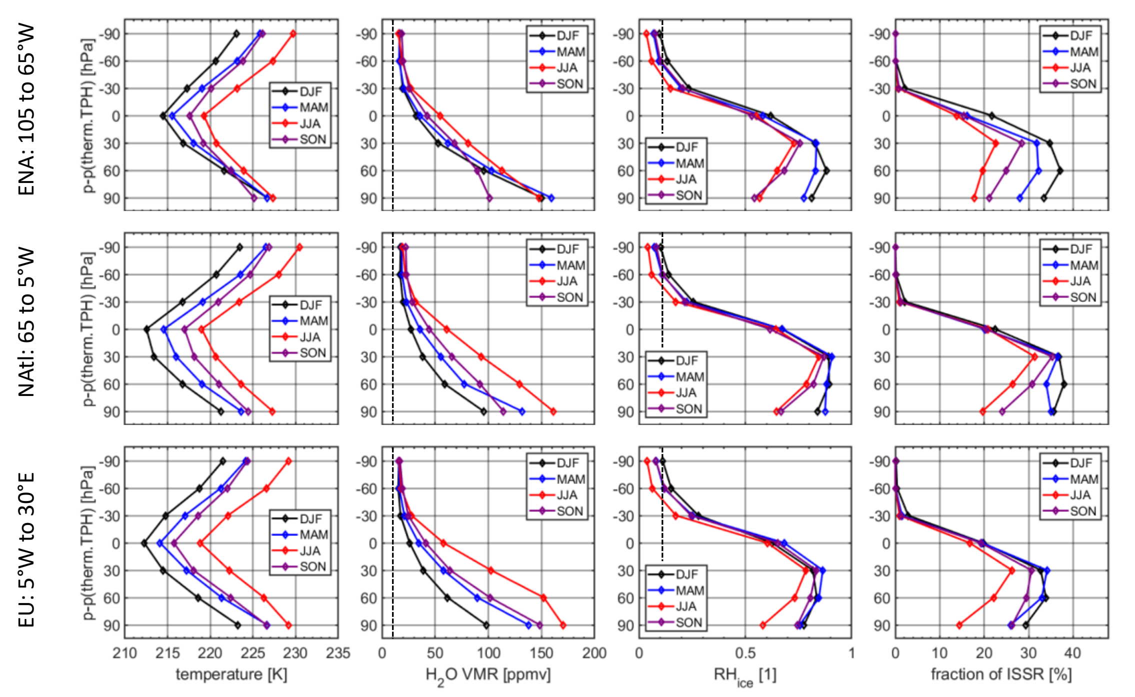
=> **The therm. TPH is seen as an transport barrier for troposphere-stratosphere exchange, it is the centre of the tropopause mixing layer ExTL.**

=> **The dyn. TPH is used for separating tropospheric and stratospheric air masses in studies on stratosphere–troposphere transport and represents the lower bound of the ExTL.**

Thouret et al. (JGR 2006), WMO (1957), Hoor et al., 2004; Pan et al., 2010; Gettelman et al., 2011

VERTICAL DISTRIBUTION OF THERMODYN. PROPERTIES

www.iagos.org



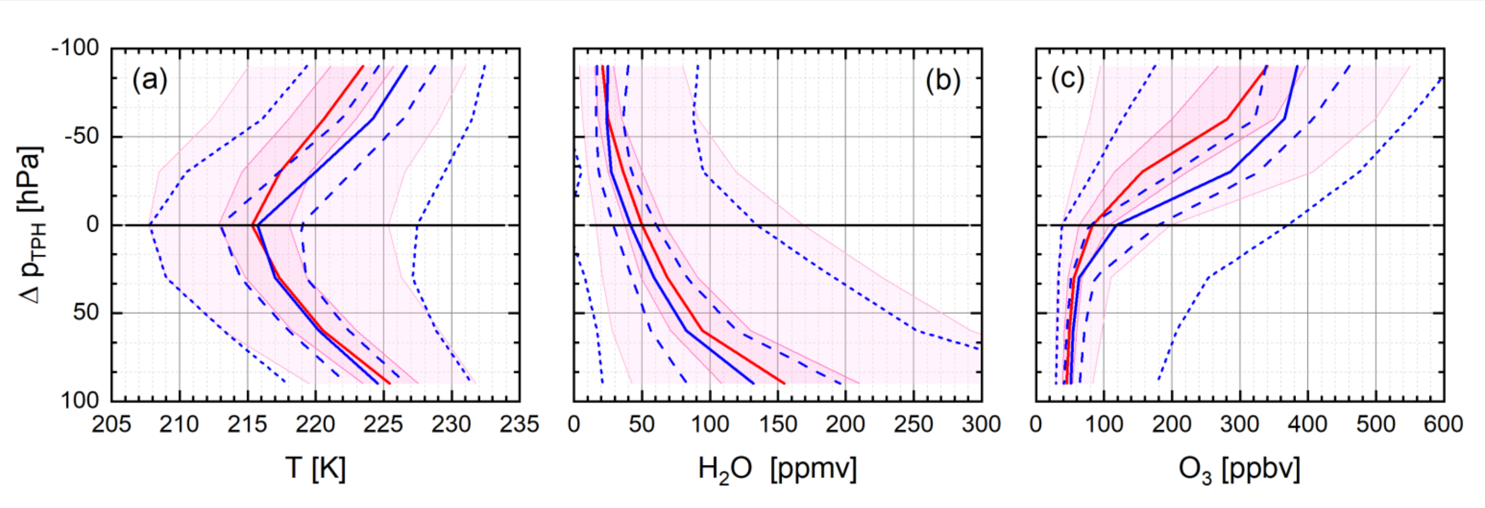
=> For all regions, the highest RH_{ice} values and the highest fraction of ISSR occurrence is observed for the two upper tropospheric layers closest to the tropopause layer whereas for the third layer situated deepest inside the UT, RH_{ice} values and ISSR fractions are considerably lower.

=> Only in the spring season over the North Atlantic, the lowest third layer reaches similar values for RH_{ice} values and ISSR fractions as the two layers above.

- Vert. distribution of T, H2O VMR, RH_{ice} and fraction of ISSR for seven 30 hPa press. layers around $p_{therm.TPH}$
- Dotted lines indicate 2-σ limit of detection of RH_{ice} = 12% and the resulting H2O VMR of 10 ppmv.

GRADIENTS OF T, H2O VMR AND O3 VMR FOR THE NORTH ATLANTIC REGION

www.iagos.org



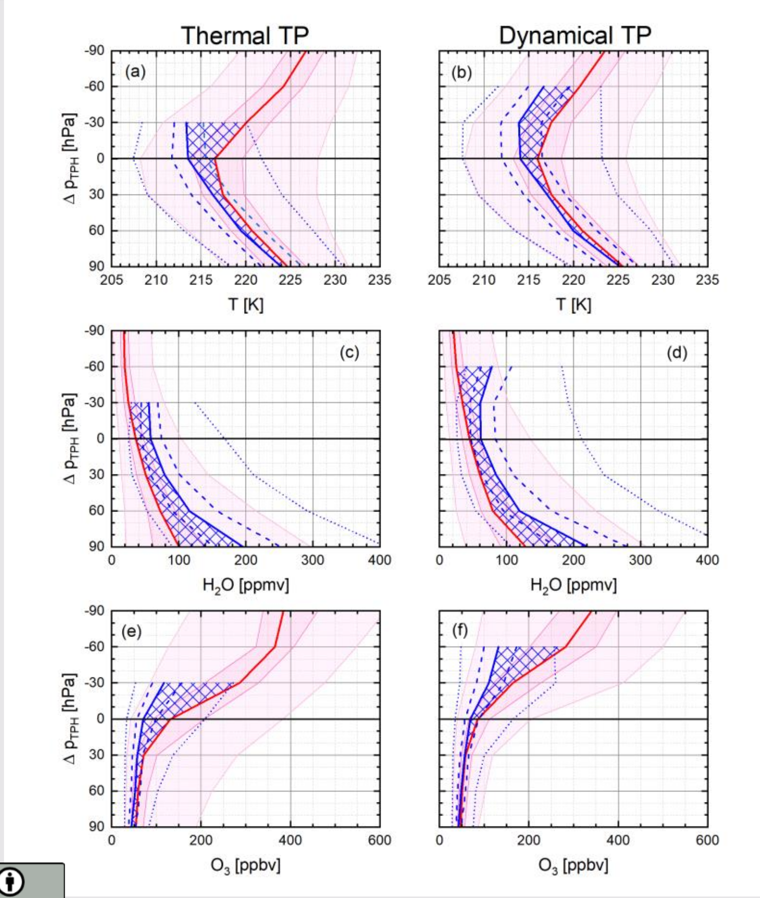
- Vertical distribution of temperature T (a), H2O VMR (b), and O_3 VMR (c) relative to $p_{dyn.TPH}$ and to $p_{therm.TPH}$ in the North Atlantic region
- Vertical distributions relative to the thermal tropopause are presented as percentiles [1, 25, 50, 75, 99] by blue lines and relative to $p_{dyn.TPH}$ conditions by red-shaded areas.

=> The temperature gradient is sharper across therm. tropopause compared to dyn. tropopause.

=> Good agreement between ERA-Interim $p_{therm.TPH}$ (ΔpTPH = 0 hPa), lowest temp. detected at ΔpTPH = 0 hPa, and chemical tropopause, indicated by O_3 VMR = 120 ppbv at ΔpTPH = 0 hPa.

GRADIENTS OF T, H2O VMR AND O3 VMR FOR ISSR AND ICE-SUBSATURATED AIR MASSES

www.iagos.org



- Vertical distribution of T, H_2O VMR, and O_3 VMR for ISSR relative to $p_{therm.TPH}$ (a, c, e) and $p_{dyn.TPH}$ (b, d, f).
- ISSR conditions are presented as percentiles [1, 25, 50, 75, 99] by blue lines and non-ISSR conditions by red-shaded areas.
- Blue cross-hatched areas highlight the deviation of median values inside ISSR from those non-ISSR conditions.

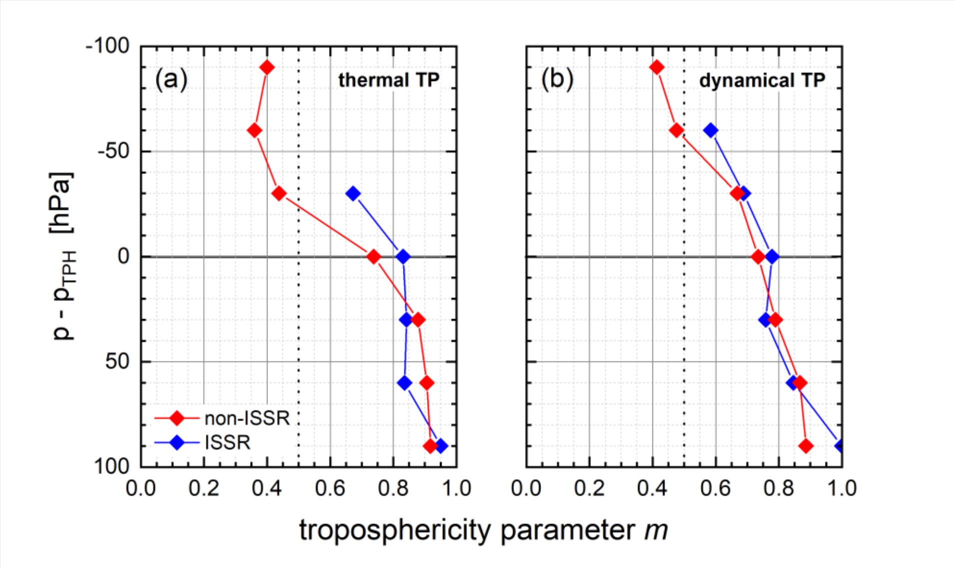
=> Ice-supersaturated air is generally colder and more humid associated with higher RH_{ice} and – in case of observation inside or above the tropopause layer - carries less O_3 than the surrounding air masses.

=> This is in close agreement with reported results for T and RH_{ice}

(Gierens et al., 1999; Spichtinger et al., 2003)

Vertical distribution of the tropophericity

www.iagos.org



Vertical distribution of the tropophericity parameter m for ISSR and non-ISSR air masses with respect to the thermal (a) and dynamical (b) tropopause.

Using O_3 VMR as stratospheric air mass tracer, we define the tropophericity parameter m (Cirisan et al., 2013) for an ensemble of data characterised by median (med) and 99 percentile (P99) values as:

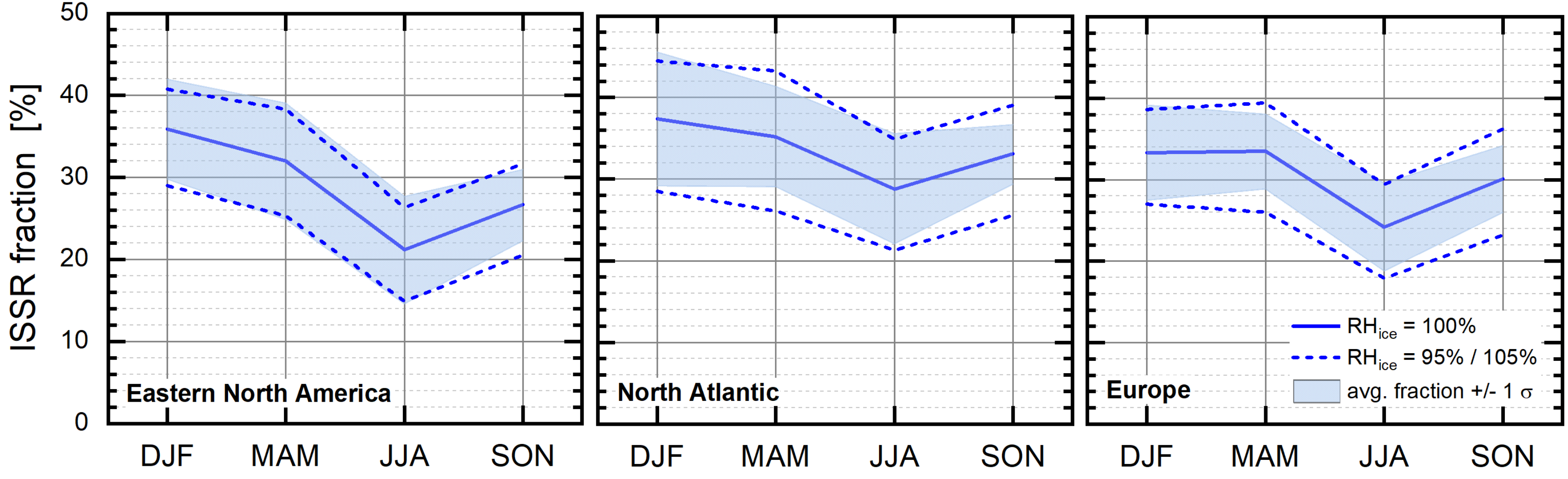
$$m = \frac{[O_3]_{P99} - [O_3]_{med}}{[O_3]_{P99} - [O_3]_{tropo}}$$

$[O3]_{tropo}$ = 42 ppbv (median value of the lowest layer)

=> A significant impact of tropospheric air even on ISSR is observed above the therm. tropopause.

=> The thermodynamic features together with the increased tropophericity indicate vertical mixing in the vicinity of the tropopause layer as one important formation process of ice-supersaturation.

Seasonal Variation of ISSR Fraction

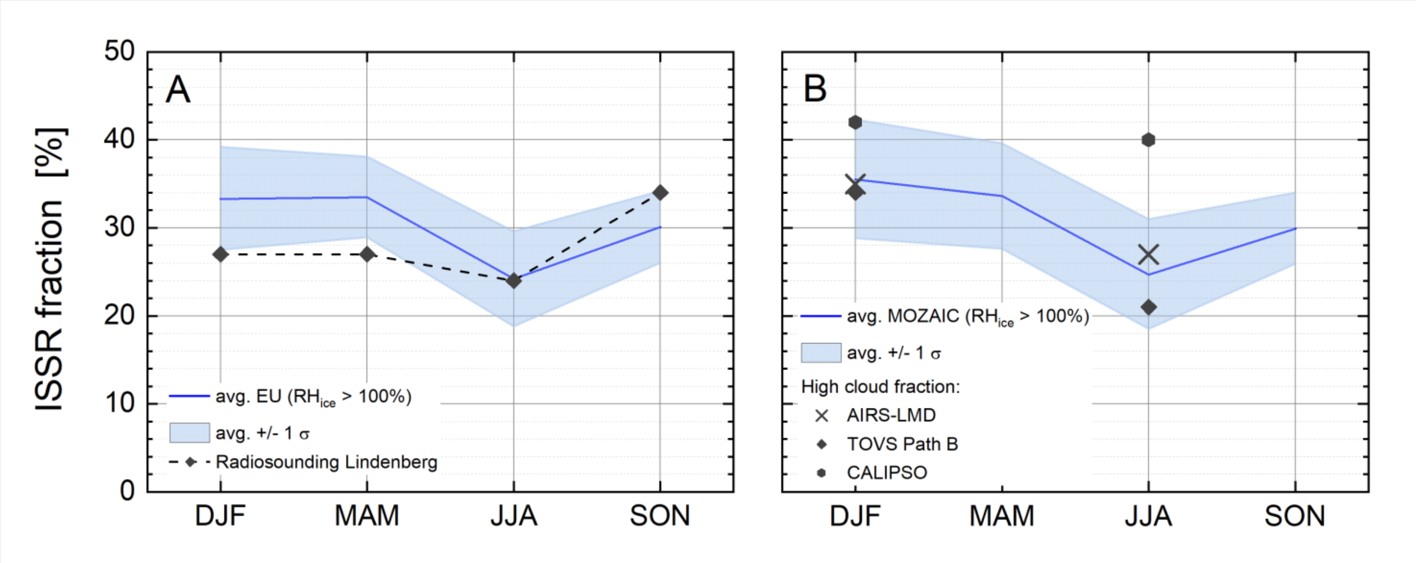


- Annual cycles of ISSR occurrence shown as occurrence probability for RH_{ice} > 100% (1995 to 2010)
- Shaded areas represent probabilities for the average value (thick lines) ±1σ
- Short-dashed lines represent average fractions for RH_{ice} = 95% and 105%

=> **Detailed seasonality of ISSR occurrence over different regions.**

SEASONAL VARIATION OF ISSR FRACTION

www.iagos.org



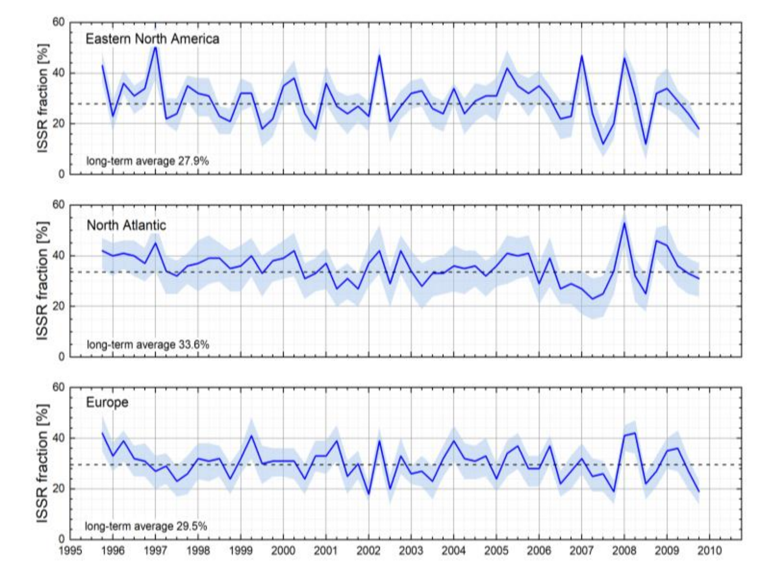
A Seasonal cycle of ISSR occurrence probability, i.e. p(RHice > 100%) for Europe (1995 to 2010) symbols show annual cycle of Lindenberg sounding (2000 – 2001) from Spichtinger et al. (2003)

B Seasonal cycle of ISSR occurrence probability, as p(RHice > 100%) for Northern ML (1995 to 2010) symbols represent high cloud fractions from cloud climatology by Stubenrauch et al. (2010)

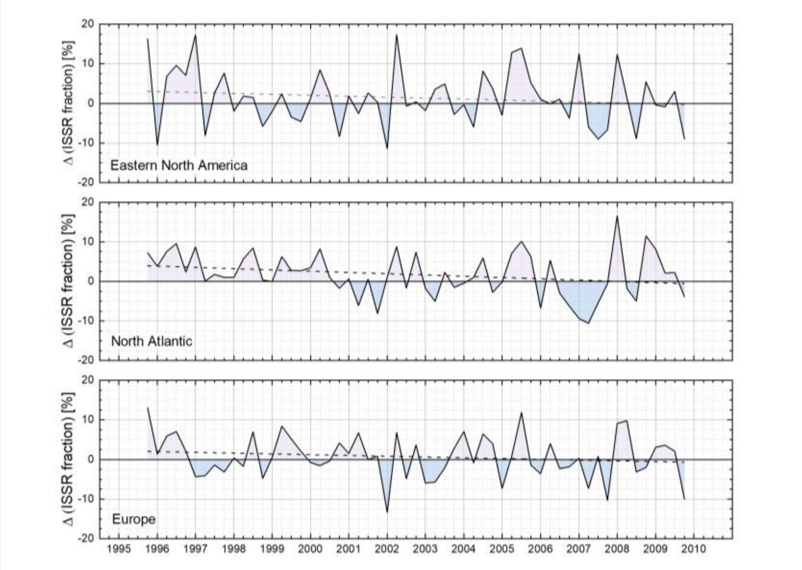
=> Close agreement between the different observations of seasonal cycles of ISSR occurence.

TIME SERIES OF ISSR FRACTION

www.iagos.org



Time series of ISSR fraction



De-seasonalised time series of ISSR fraction

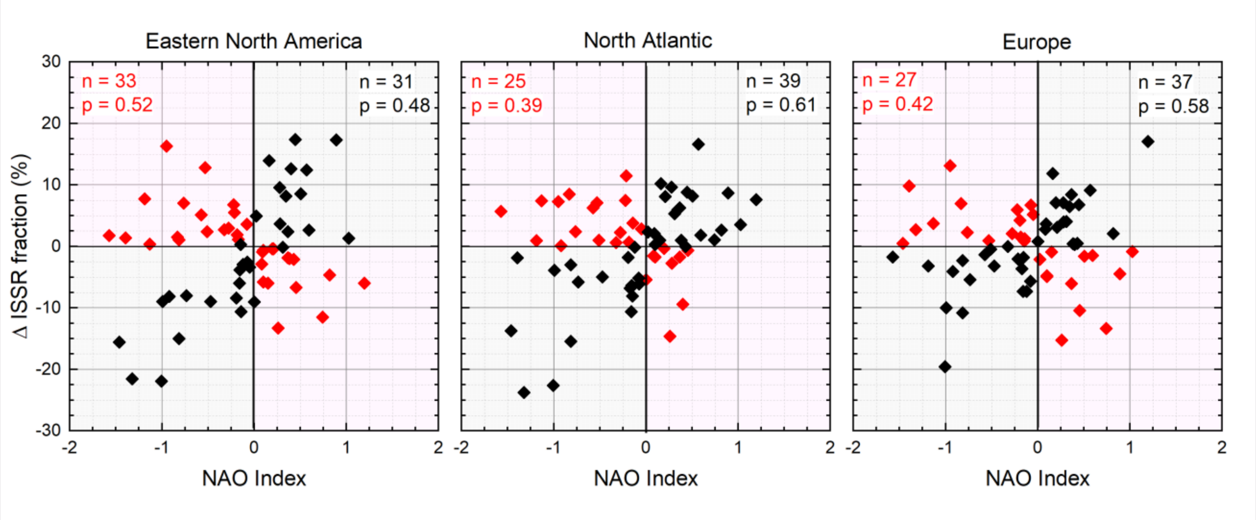
- Solid lines: average fraction for RH_{ice} = 100%.
- Shaded areas: average fractions for RHice = 95- 105%.

=> Over the investigated period of 15 years, no significant trends are observed, neither for the occurrence of ISSR nor for the deviation of seasonal ISSR occurrence probabilities from the long-term average.

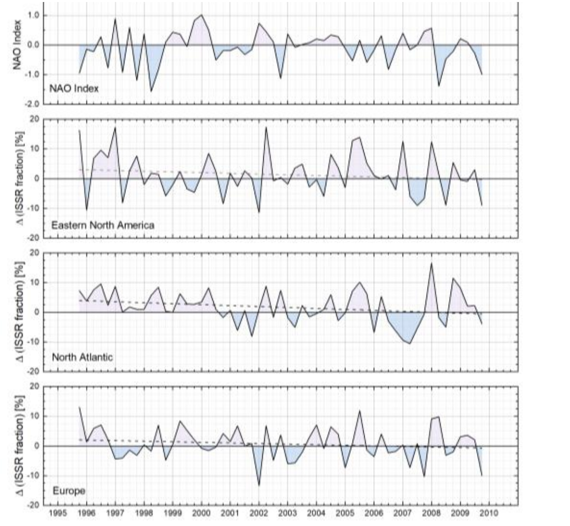
NAO INDEX AND ISSR FRACTION

www.iagos.org

NAO index > 0 => Δp (Iceland low to Azores high) larger than average



NAO index = deviation of Δp (Iceland L to Azores H) from average



- Correlation analysis with respect to the correlation of signs between NAO index and deviation of ISSR occurrence from the long-term average (Δ ISSR) for the target regions; Numbers indicate the results from the correlation analysis with respect to number of samples n, Pearson R and significance level p.
- We identify a significant correlation of signs between the NAO index and the deviation of seasonal ISSR occurrence probabilities from the long-term average for the North Atlantic.

=> Stronger westerlies bringing moist air to Europe higher probability for ISSR occurrence.

SUMMARY

www.iagos.org

IFC @ MOZAIC data set — RH_{ice} distribution within physical boundaries:
$RHi_{ice,\,min} \geq 0\%$, $RH_{ice,\,max} \leq RH_{ice,\,hom}$

Seasonality of ISSR occurrence — highest/lowest probability in late winter/summer:
$\Rightarrow$ very good agreement with radio soundings
$\Rightarrow$ very good agreement with high cloud fraction from satellites

15 years data record — no significant trends in RH_{ice} and ISSR fraction for all study areas

ISSR fraction and NAO index — correlation over North Atlantic and Europe
NAO index > 0 $\Rightarrow \Delta p$ (Iceland low to Azores high) larger than average
stronger westerlies bringing moist air to Europe
higher probability for ISSR occurrence

Live chat : Tuesday, 05 May 2020, 14:00-15:45, session AS3.5